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Prism Adaptation in Virtual Reality: a single-blind study in healthy subjects

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CONTENTS

Chapter 3

ADAPTATION TO VIRTUAL PRISMS: A SINGLE-BLIND DOSE-RESPONSE STUDY IN HEALTHY SUBJECTS

Given the mixed results previously discussed, it is possible to conclude that this divergence of findings simply reflects the variability of symptoms associated with spatial neglect, or that the gains that can be obtained from PA are essentially random. However, at closer look several factors emerge that may systematically contribute to the outcome of PA rehabilitation.

First, PA may affect visuomotor performance more than purely perceptual measures (Ptak, 2017; Striemer & Danckert, 2010b). For example, PA was found to improve performance better in the classic line bisection task than in the landmark task (Harvey, Milner, & Roberts, 1995), which requires judging the accuracy of line pre-bisections (Striemer & Danckert, 2010a). In addition, patients with motor-intentional or 'aiming' deficits (i.e. “impairment at output-related stages disturbs spatial action planning and execution”) appear to benefit more from PA than patients with purely perceptual deficits (Fortis, Chen, Goedert, & Barrett, 2011; Goedert, Chen, Boston, Foundas, & Barrett, 2014). According to this, Striemer and Danckert (2010a) argued that PA on neglect patients could impacts more on dorsal stream process than on ventral stream ones (i.e. perceptual biases). Meanwhile, PA seems to influence either motor or perceptual biases in normal subjects (Loftus et al. 2008; 2009). Together, these observations suggest that such differential effects may be explained by the dorsal-ventral streams connections. In fact, an inferior parietal cortex lesion – generally present in neglect patients - could disrupt the normal dorsal-ventral connectivity (Milner and Goodale, 2006) hampering the PA influence on perceptual process (Striemer and Danckert, 2010a). These findings are consistent with Redding & Wallace's (2006) proposal that the main mechanism responsible for PA effects in neglect patients is the leftward recalibration of the coordinates of a motor-sensory reference frame.

A second observation is that PA effects may depend on the degree of spatial error induced by the prisms. Some authors have called for studies evaluating the dose-response to prisms of different deviating powers (Barrett et al., 2012). Indeed, Facchin, Beschin, Toraldo, Cisari & Daini (2013) found that the after-effect was maximally 33% of the angular deviation of the prisms, and that in neglect patients prisms with a greater number of dioptres induced the largest effects. Similarly, the effect of PA on line bisection judgments in healthy participants was demonstrated to depend on the degree of deviation (Michel & Cruz, 2015). Small deviations may thus fail to produce transfer to other tasks because the size of the adaptation effect is too small to be of any significant. Unfortunately, there is an optical limit to the technology, that is wedge prisms with more than 20 dioptres not only displace the field of view, but also add optical aberrations and may produce significant discomfort.

Third, transfer effects from PA seem to depend on the direction of the spatial deviation. While neglect patients benefit from prisms with rightward deviation, healthy controls generally show transfer to visuospatial tasks only when they are adapted with leftward deviating prisms (Michel, 2016; Schintu et al., 2017). However, inducing neglect-like behaviour in healthy participants is not the same as alleviating neglect with PA in patients. It is therefore unclear to what extent the induction of such neglect-like bias in controls can be considered as a model of PA effects in neglect patients. The reason for the absence of cognitive transfer effects after rightward deviation in healthy participants is unknown, but one possibility is that effects may only appear with optical deviations that are comparatively larger than when leftward deviating prisms are used.

A final question concerns adequate blinding, which is a major issue for rehabilitation studies. Several of the RCTs cited above were performed using a single-blind design, where patients either underwent PA or performed pointing movements with non-deviating goggles. However, even if patients are blind about the type of goggles they are wearing, and their reports suggest no awareness of the optical deviation (Rode et al., 2015), the compensation (and thus, the after-effect) relies on the perception of the mismatch between target and hand position. The PA technology thus precludes complete blinding of subjects.

We addressed these points in an experimental study on healthy participants, by using virtual reality as an alternative to wedge prisms. In a virtual environment different degree of spatial error between hand and target can be induced without any discomfort for the participant. For example, a study showed how it is possible to interfere on visuo-motor performances using virtual technologies (Bagce et al., 2011). In particular, 10 healthy subjects were asked to perform a simple finger flexion movement to a 45° virtual target angle. At the same time, participants received three different visual feedbacks online: the real one, where the hand movement perfectly matched with the virtual one; a scaled-down/scaled-up feedback, where the hand movement was 25% or 175% scaled compared to the real one. Even though participants were instructed to perform the same movement, the visual shifts led to a significative online adaptation (respectively increasing and decreasing).

The following year, Bagce and colleagues tested the same paradigms on post-stroke spasticity patients (Bagce et al., 2012) exploring also the cortical excitability M1 area. Together with the online adaptation during the task, results showed a facilitation effect in scaled-down condition measured through MEPs. These outcomes suggest that VR-based tasks may allow to generate visuo-motor mismatches both to alter the sense of ownership and to prompt a dynamic sensory-motor adaptation through an effect of neuromodulation (Bagce et al., 2011).

In addition to this, another main advantage offered by the VR setting software, is that it is possible to progressively induce the mismatch, which makes it difficult for the subject to become aware of the manipulation. By making use of these features of virtual prisms we tested whether rightward optical deviations of up to 30 degrees affect manual and perceptual judgments in healthy participants.

3.1. MATERIALS AND METHODS

3.1.1. PARTICIPANTS

Forty-eight healthy subjects (34 women, mean age 22.8 ± 3.3 years) participated to the study. Forty-three participants were classified as right-handers and five as left-handers based on scores on the Edinburgh Handedness Inventory (Oldfield, 1971). None of them had motor disorders and all had normal vision. Given that this is the first study using virtual reality to induce adaptation effects we did not perform an a priori power analysis. Based on comparable studies using wedge prisms (e.g., Michel & Cruz, 2015) we determined that a group size of 12 should be adequate to reveal significant findings while avoiding trivial effects. Participants were randomly assigned to one of four groups (12 participants per group), defined by different degrees of optical deviation during adaptation: 0 (no deviation), 10, 20 or 30 degrees of deviation. One subject was replaced due to a technical error. All participants gave informed consent and the study was approved by the ethical commission of the canton of Geneva.

3.1.2 STIMULI AND PROCEDURE

A Vive VR system was used to present the stimuli and to induce an optical shift during adaptation (see Figure 7). Participants were seated and asked to hold a controller in their dominant hand. The controller had a button similar to a gun trigger, and its position was tracked in real-time by the system and reproduced in virtual space. The VR headset had a field of view of 110 degrees at a refresh rate of 90 Hz, and the system was calibrated so that the origin of the of three-dimensional virtual space was aligned with the midline of the subjects' trunk. In order to induce adaptation, the 3D-coordinates of the controller were modified by adding a fixed amount, so that the image of the controller appeared displaced by 0, 10, 20 or 30 degrees rightward from its real position. It should be noted that the principle of adaptation when using virtual reality is slightly different from that of wedge prisms. In contrast to virtual reality wedge prisms affect the entire visual field (including the pointing target), shifting it in one direction.

Figure 1. Vive VR system (HTC Corp., Taoyuan, Taiwan).

Since participants only see their hand in the end part of the pointing movement they initially aim toward the perceived (i.e., shifted) target position and only correct their movement once their hand becomes visible through the goggles. In virtual reality subjects never see their arm, but a representation of the controller. In addition, the pointing target only exists in the virtual space, and its perceived position is always its real position. A shift of the target position therefore does not create a mismatch between hand and target. In order to induce adaptation effects, we shifted the perceived position of the controller relative to its real position. However, given that the controller is always visible, when using large deviations subjects might become aware that the location at which it is shown does not correspond to the real (proprioceptive) position of their hand. For this reason, rather than inducing it instantaneously we increased the shift incrementally in small steps while subjects were performing pointing movements. Each subject participated to one experimental session, consisting in: testing before adaptation (baseline), adaptation, testing after adaptation and recalibration. Each of the four phases was followed by a test of open-loop pointing as measure of the adaptation effect (open-loop pointing before recalibration was performed in order to measure the decay of sensorimotor adaptation effects) (see Figure 8). All tasks were performed with the dominant hand. At the end of the experimental session, the subjects were asked to complete a questionnaire assessing their awareness of pointing performance and target deviation.

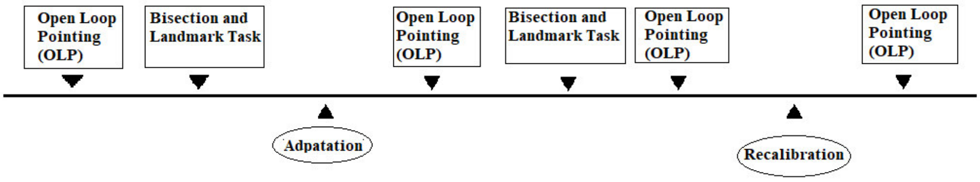


Figure 2. *Time course of the experiment.*

Adaptation and recalibration

Adaptation. Subjects saw the projection of 3 x 3 black spheres in front and approximately at arm length (≃70 cm) in virtual space. The image of the controller was replaced with the image of a white rod [see Figure 9, respectively a) and b)]. No stimuli or cues other than the nine spheres and the virtual rod were visible. At the beginning of each trial, one sphere turned red and the participant was instructed to touch it. The position of the red sphere varied randomly across 100 trials. During pointing, a progressive visual shift of the controller position was induced: at the onset each subject saw the rod at the position corresponding to the real position of the controller (0 degrees deviation). Across two minutes (i.e., approx. 50-70 pointing movements) its position gradually shifted by a small amount to the right until it reached the desired displacement of 10, 20 or 30 degrees of visual angle (depending on the group to which participants were assigned). Hence between two successive trials the position of the virtual rod moved

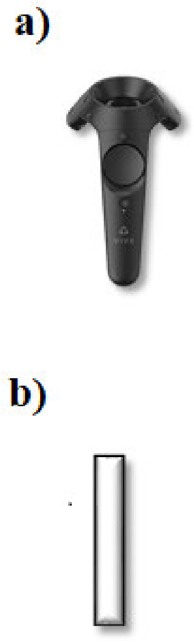


Figure 3.

rightward only in very small steps (~0.15 - 0.5 degrees per trial). This procedure allowed us to induce a deviation without the subjects noticing it (see results of the awareness questionnaire).

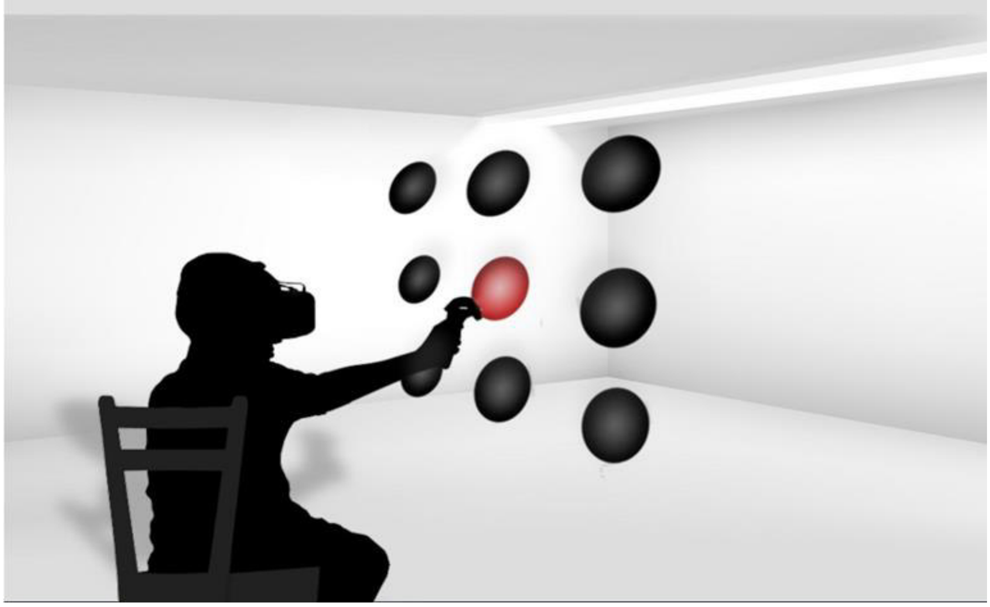


Figure 4. Pointing task during the Adaptation and Recalibration phase.

Recalibration. Recalibration was identical to adaptation, except that no visual shift was induced, and all four groups thus pointed with 0 degrees deviation (see Figure 10).

After and transfer effects

Effects of adaptation (namely the after-effect) were evaluated with open-loop pointing (OLP) at four different time-points. Transfer effects were examined with two variants of the line bisection task (line bisection and space bisection) and two variants of the landmark task (line landmark and space landmark). These four variants were used in order to dissociate sensorimotor transfer (which should be observed in line and space bisection) from perceptual transfer (observed in both landmark tasks). In addition, lines and spaces were used to test within-object coding (present in the line bisection and line landmark tests) and space-based coding (present in the space bisection and space landmark tasks). The four bisection tasks were performed in random order.

Open-loop pointing (OLP). A black dot (2.6 degrees of visual angle) was projected exactly in front of the subject, centred on her/his sagittal midline.

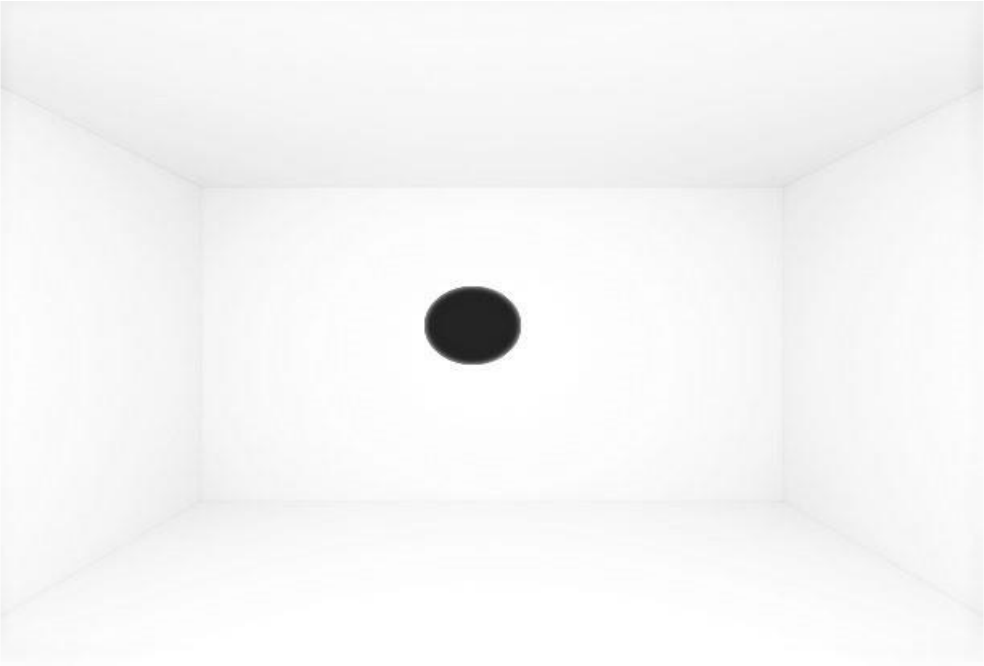


Figure 5. Subject's view of black dot during the Open loop pointing task.

The virtual environment showed a monotonous white space and it was therefore devoid of any cues that could bias open-loop pointing. Visibility of the controller was turned off and subjects did not see their body or arms, so that there was no visual feedback about performance. The subjects were asked to hold the controller at chest height (start position), to reach toward the target and to press the controller button (see Figure 11). The trial was repeated 5 times for each evaluation.

Line bisection. Participants were asked to bisect a series of black lines presented in a completely white virtual environment. Lines were projected at a distance of 50 cm in front of the subject, centred on the body midline. They were 35, 50 or 65 degrees of visual angle, and their width was 1.15 degrees. The controller was visible and projected a red light from its tip that subjects directed at the line to ‘cut through’ it at its estimated midpoint

(Figure 12). Participants performed four trials for each line length for a total of 12 trials.

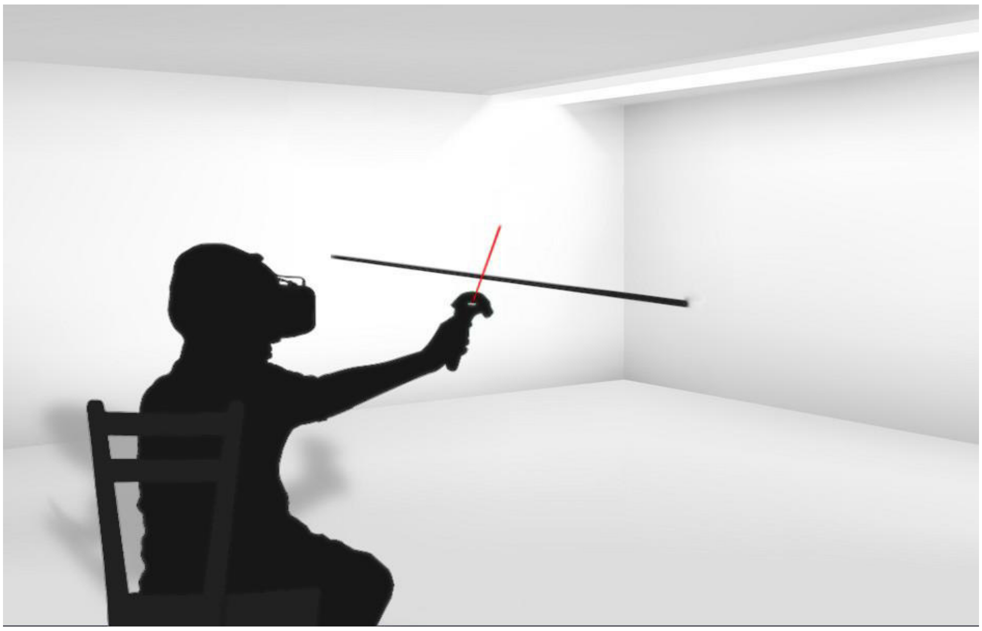


Figure 6. Illustration of Line Bisection task.

Space bisection. The task was identical to the line bisection task except that instead of the line only two vertical lines (length: 11.4 degrees of visual angle) were visible as delimiters of the left and right border of a space that should be bisected (Figure 13).

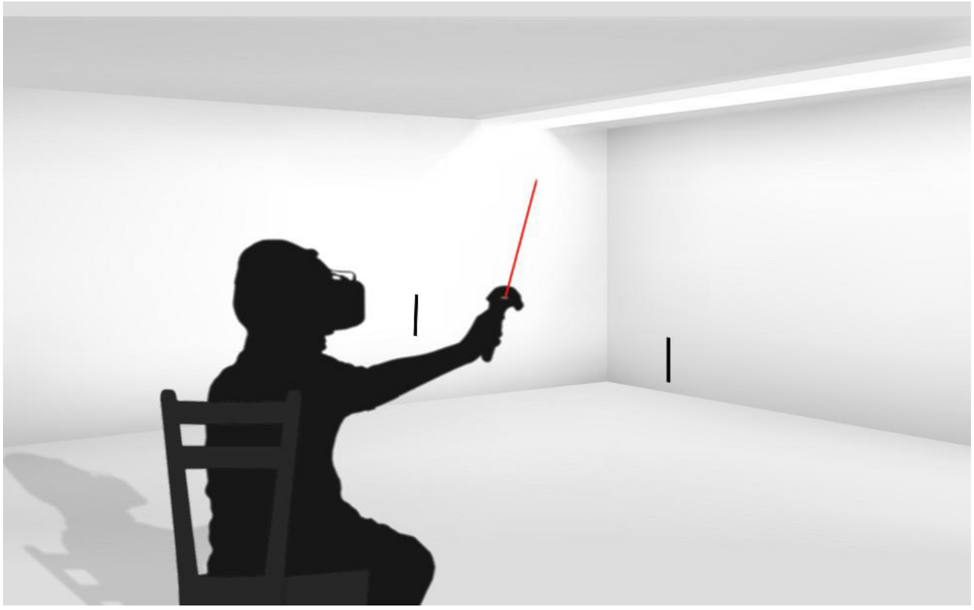


Figure 7. Illustration of Space Bisection task.

Line landmark task. The stimuli were identical to the line bisection task, except that a red vertical mark (length: 11.4 degrees) bisected the line either in its centre or displaced by 2, 4, 8, or 16% of the total line length to the left or right of the centre. Participants were asked to indicate whether the bisection mark was bisected in the centre or to the left or right [Figure 14]. There were 9 trials for each line length, resulting in a total of 27 trials. In order to evaluate the subjective centre in numerical terms we calculated a subjective bias score, computed as follows: zero was assigned every time the subject's answer was correct. An error was coded numerically by assigning a score that represented the degree of deviation of the bisecting line. For example, when the subject said ‘centre’ or ‘right’ for a line that was bisected at -2%, a value of +2 was assigned to this trial, while for a line bisected at +4% a value of -4 was given. The subjective bias was computed as the median of all scores obtained from the 27 trials, by excluding trials in which the line was bisected in its centre. A positive bias indicated that the subjective centre was shifted to the right (i.e., that the left side was perceived as longer), while a negative bias indicated a shift toward the left.

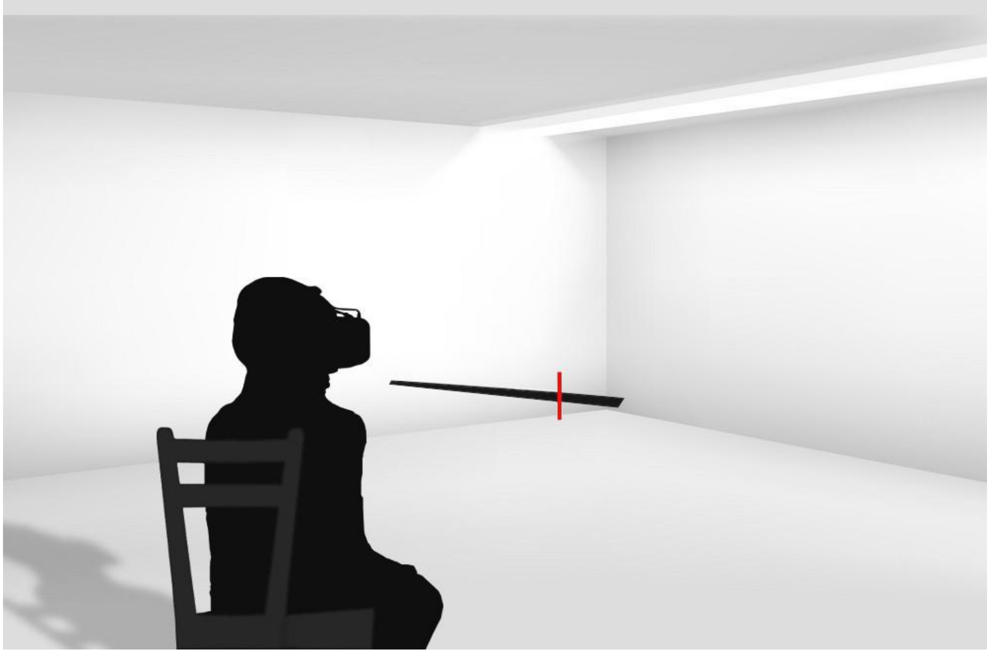


Figure 8. Illustration of Line Landmark task

Space landmark task. The task was identical to the line landmark task except that only the borders of a delimited space (as in the space bisection task) as well as the bisection mark were shown (Figure 15).

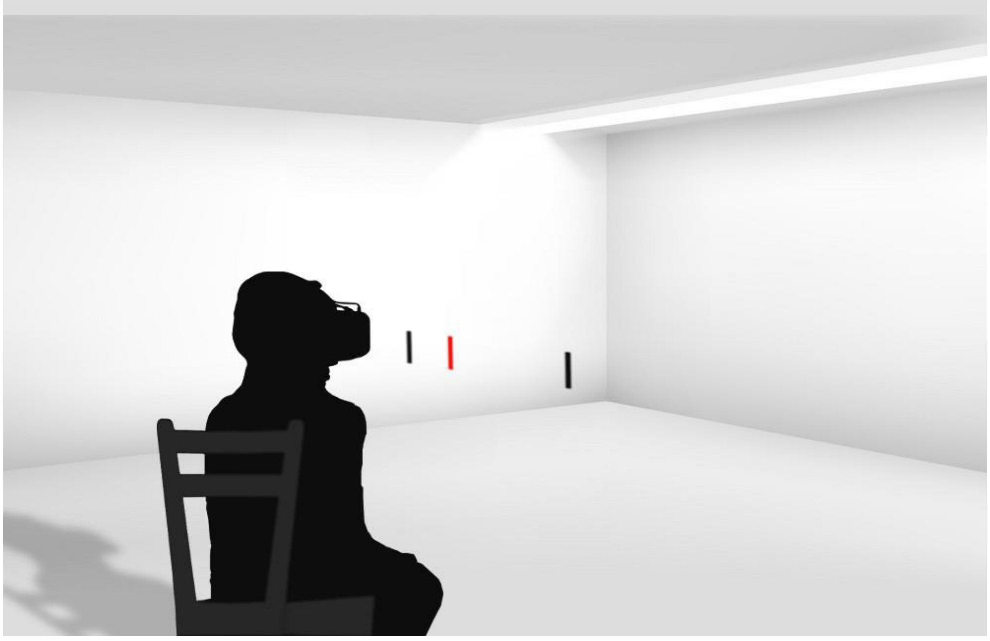
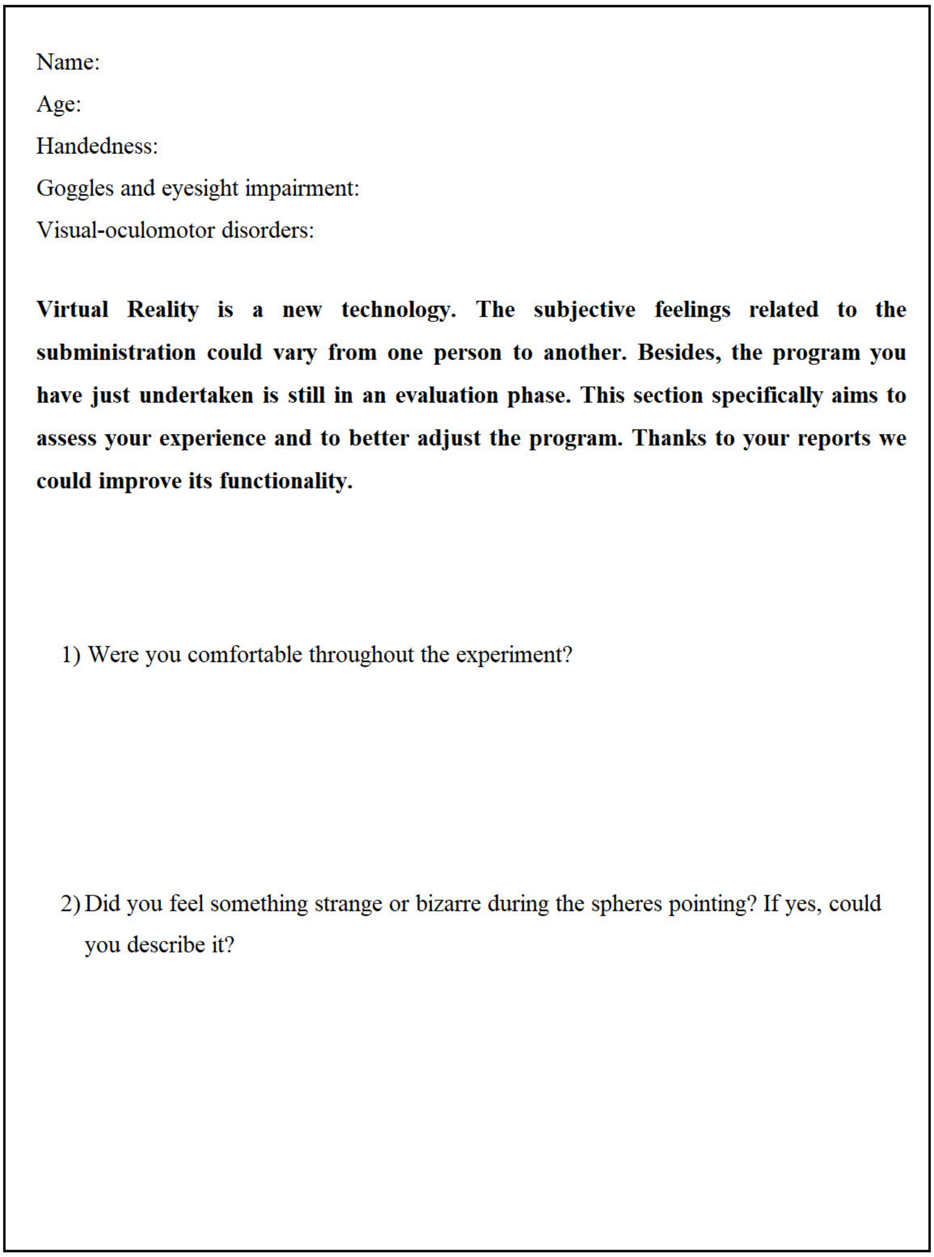


Figure 9. Illustration of Space Landmark task

Awareness evaluation

The awareness questionnaire aimed to assess participants' perception of the mismatch between the reached targets in the adaptation task and the controller as well as their awareness of visuomotor adaptation effects. It started with an open question probing any awareness of the visual shift ('Did you feel something strange or bizarre when you were reaching for the spheres? If yes, could you describe it?'). The following questions assessed awareness of adaptation more directly and they were composed of a series of questions about the open-loop pointing task that had to be rated on a five-point Likert scale ranging from 'strongly agree' to 'strongly disagree '(e.g., 'I felt that my hand did not aim towards the target') [see the next two pages for an example].



Name:
Age:
Handedness:
Goggles and eyesight impairment:
Visual-oculomotor disorders:

Virtual Reality is a new technology. The subjective feelings related to the subministration could vary from one person to another. Besides, the program you have just undertaken is still in an evaluation phase. This section specifically aims to assess your experience and to better adjust the program. Thanks to your reports we could improve its functionality.

1) Were you comfortable throughout the experiment?

2) Did you feel something strange or bizarre during the spheres pointing? If yes, could you describe it?

Figure 10. The awareness questionnaire - Part 1.

In this section, we ask you specifically to focus on task where you had to point to black dot.

	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
It seemed to me that the point was not right in front of me.					
It seemed to me that I did not point in the right direction.					
It seemed to me that my hand was displaced compared the black dot position.					
It seemed to me that my hand was displaced to the left.					
It seemed to me that my hand was displaced to the right.					
It seemed to me that my hand was displaced 10 cm from the black dot.					
It seemed to me that my hand was displaced 20 cm from the black dot.					

Figure 11. The awareness questionnaire - Part 2.

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